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Physical and chemical characters, phytoplankton and primary production of Ezequiel Ramos Mexía Reservoir (Argentina)

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Abstract

We describe the distribution in space and time of a series of physical and chemical variables, phytoplankton, and primary production in Ezequiel Ramos Mexía Reservoir (Argentina). Its waters are soft, poor in nutrients and with a low transparency that greatly depresses primary production. Phytoplankton data indicate the presence of 79 taxa with Bacillariophyceae, Cyanophyta and Chlorophyta alternatively dominant. Chlorophyll *a* was always low and never exceeded 3 mg m^{-3}. Based on these results, the trophic status of this ecosystem is discussed.

Introduction

Ezequiel Ramos Mexía Reservoir was formed by damming of the Limay River during 1972, and is located at 39° 50′ S and 69° 20′ W (Argentina). Little research has been done on the physical, chemical and biological aspects of this ecosystem. Land de Castello (1981) gives a description of the abiotic characteristics of the Limay River in the Alicura area; Guarrera *et al.* (1985 & 1987) studied the taxonomics of its Chrysophyceae, Chlorococales and Chamaesiphonales, and Echenique *et al.* (1988) made a comparison of phytoplankton biomass in E. Ramos Mexía and Arroyito Reservoirs.

Several dams are being built in the Limay drainage basin for hydroelectric purposes, and this is expected to have a marked effect on water quality. The objective of the present paper is therefore to provide basic information about the physical and chemical characteristics, phytoplankton and primary production of this reservoir, and to identify its trophic status.

Description of the study area

Morphometric data are given in Table 1. The Limay River Valley is formed by well-graded gravel of clastic pebbles with diameters between 1 and 3 cm, and 30% of sand. The thickness of mantle varied from 10 to 30 meters. The stratigraphic succession of the region around the lake is composed of three kinds of sediments: a) cretaceous sediments, emerging on both sides of the reservoir in a continous way. They are formed of sandstone, sandy claystone, siltstone and clay. The clay is of the montmorillonite group, with low permeability; b) modern sediments, formed by polymictic conglomerates of variable granulometry, with clasts no bigger than 10 cm in diameter, sandy and clayed matrix and c) recent sediments, of fine to very fine sand, forming dunes up to seven meters high, predominantly in the northeast of the lake.

Material and methods

Monthly surveys were made from January 1981 to June 1982 at a single pelagic station (Fig. 1), taking samples at 0, 1, 2.5, 5, 7.5, 10, 20 m and at 1 m above the bottom. Samples for chemical analysis were also obtained from Limay and Collón Cura Rivers.

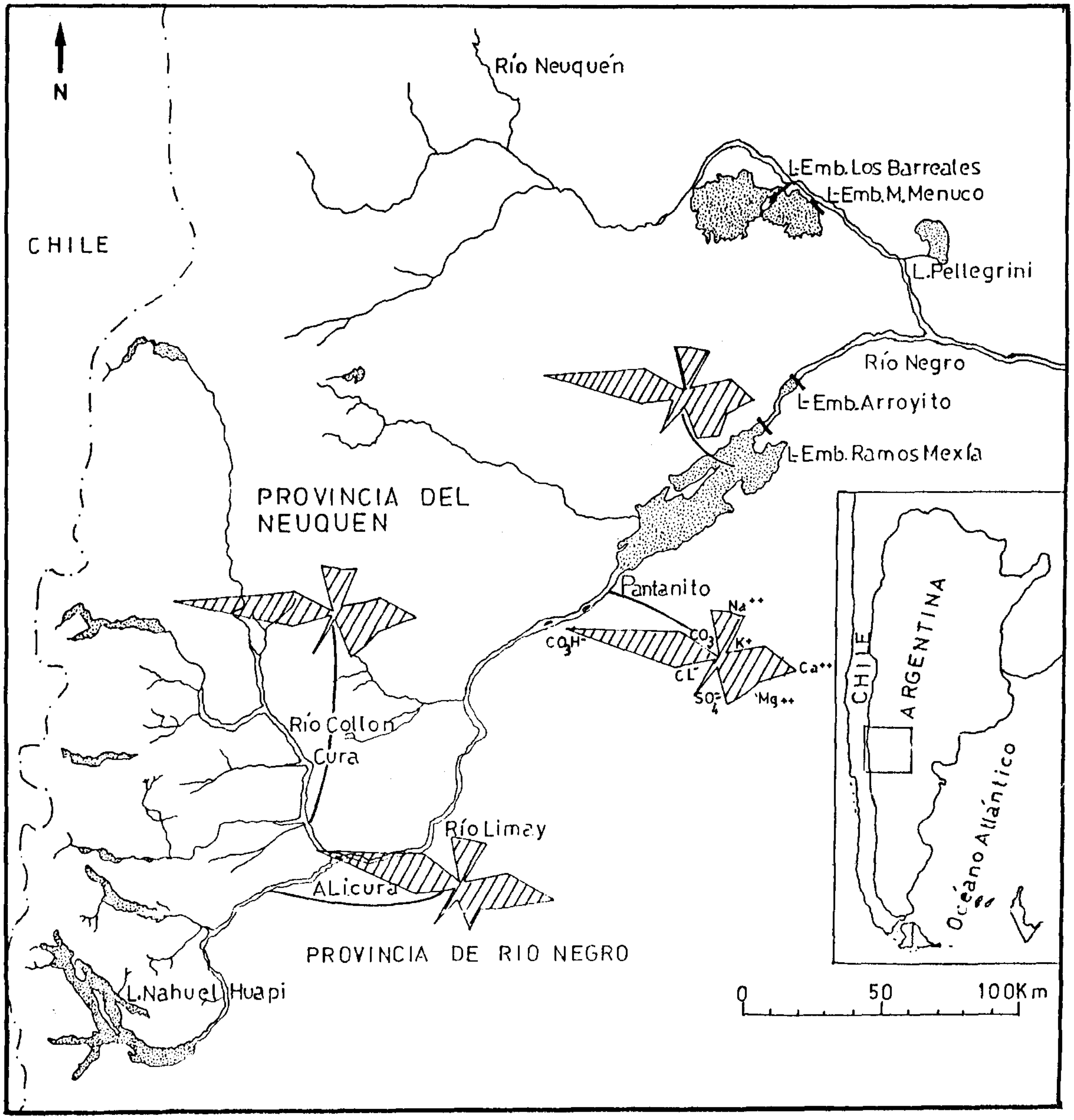

Fig. 1. Geographical location of the Ramos Mexia Reservoir and its affluents with their ionic composition of the data.

Table 1. Morphometric parameters of E. Ramos Mexía Reservoir.

Surface area	816 Km^2
Volume	20,200 hm^3
Maximum depth	60 m
Mean depth	24.7 m
Maximum length	59.5 Km
Maximum breadth	13.7 Km
Shore line	346 Km
Development of shore line	3.4
Catchment area	24200 Km^2
Mean residence time	365 days

Water samples for chemical analysis and photosynthetic pigments were taken by pumping and for phytoplankton and primary production by Van Dorn bottle. Samples were immediately analyzed in laboratories sited on the Reservoir shore. Water temperature was measured directly from the pumping pipe with a thermometer. Transparency was determined with a Secchi disc, light extinction with a Li-Cor underwater photometer (Lambda Instruments, USA), dissolved oxygen by the Winkler method (Alsterberg modification), sodium and potassium by atomic absorption; calcium, magnesium, chloride and carbonate by volumetry; ortophosphates, total phosphorus, nitrates, ammonium, sulphates and reactive silica by spectrophotometry. The methodology used was that of Standard Methods for the Examination of Water and Wastewaters (1971) and Methods for Chemical Analysis of Water and Wastes (1976).

Samples for phytoplankton were fixed with 1% lugol solution. Counting was done according to Utermöhl (1958) and Lund *et al.* (1958). Based on this data, a diversity index was calculated applying Shannon & Weaver's formula, as modified by Lloyd *et al.* (1968).

Total chlorophyll was determined by Lorenzen's method (1967), and included phytoplankton below and above 25 μm. A pigment index was calculated using the ratio of spectrophotometric absorption at the wavelengths of 430 and 665 nm (Margalef, 1965).

Primary production was determined after Steemann Nielsen (1952) by *in situ* incubation of 100 ml light and dark bottles, inoculated with 4 μCi of sodium bicarbonate, ^{14}C. The incubation was from 10.00 to 14.00 hours. The contribution to total primary production of phytoplankton below 25 μm size was estimated by means of a previous gravity filtration and simultaneous incubation with the other samples. Radioactivity was measured with a liquid scintillation counter (Beckman LS 100), adjusting values according to a quenching curve.

Results

Temperature fluctuated between 8 °C in September 1981 and 21 °C in March 1982 (Fig. 2). There was a period of vertical mixing from March to November, while during summer a slight stratification was observed, with a maximum amplitude of 3 °C in March 1982.

Transparency ranged from 1 to 6 meters, with a mean of 3.3 meters. Figure 3a shows that the Secchi disc disappeared between 25% and 10% of incident light. The extinction coefficient varied from 0.231 m^{-1} to 0.690 m^{-1}, with a mean 0.447 m^{-1} (Fig. 3b). The latter showed a significant relation: $E = 0.750\ ml^{-1} - 0.093\ m^{-2}\ S$; $r = 0.83$; $P \leqslant 0.001$. Euphotic depth was from 6.4 to 20.4 meters with an average of 11.7 meters.

The different chemical variables are listed in Table 2. Limay River water is low in salinity; after its confluence with Collon Cura River, its concentration increases, but maintaining its ionic composition. Salinity in the lake increases around

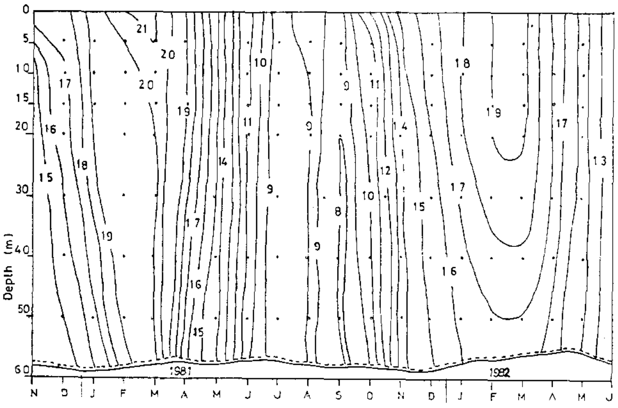

Fig. 2. Seasonal variation in temperature (°C) for Ramos Mexia Reservoir.

Table 2. Mean values ($\bar{x}$) and range of annual variation of chemical variables in Ramos Mexía Reservoir and affluents.

	Affluents						Ramos Mexía Reservoir	
	Collon cura River		Limay River (Alicura)		Limay River (Pantanito)			
	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	Range	$\bar{x}$	Range
Ortophosphate $\mu g\,P\,l^{-1}$	5	-	5	-	5	-	5	5–47
Total P $\mu g\,P\,l^{-1}$	17	5–34	8	5–11	9	5–11	10	5–53
Nitrate $\mu g\,N\,l^{-1}$	10	-	10	-	10	-	10	10–50
Nitrite $\mu g\,N\,l^{-1}$	10	-	10	-	10	-	10	-
Ammonia $\mu g\,N\,l^{-1}$	10	-	10	-	10	-	10	-
Silica mg $SiO_2\,l^{-1}$	18	17.7–18.4	12.5	10.9–13.9	16.8	15.8–17.7	13.3	11.8–15.6
Conductivity umho cm^{-1}	54	49–59	35	33–37	53	48–58	71	63–90
Carbonate mg $CO_3^{=}\,l^{-1}$	0	-	0	-	0	-	0	-
Bicarbonate mg $CO_3H^{-1}\,l^{-1}$	34.1	32.4–36.9	22.4	21.9–23.2	32	29.6–33.0	37.8	34.4–41.0
Chloride mg $Cl^{-1}\,l^{-1}$	0.5	0.3–1.5	0.8	0.6–1.5	0.6	0.5–0.7	2.0	0.0–4.3
Sulphate mg $SO_4^{=}\,l^{-1}$	1.0	0.5–1.0	2.0	1.0–3.0	1.6	0.5–3.0	2.5	0.0–4.0
Calcium mg $Ca^{++}\,l^{-1}$	6.0	5.2–6.9	5.3	3.3–7.8	5.6	3.5–6.9	6.7	0.9–13.6
Magnesium mg $Mg^{++}\,l^{-1}$	1.9	0.9–2.6	1.1	0.4–1.6	2.0	0.9–2.6	3.2	0.0–6.8
Sodium mg $Na^{+}\,l^{-1}$	3.5	3.3–3.8	2.7	2.3–3.3	3.7	3.3–4.0	4.8	3.5–6.2
Potassium mg $K^{+}\,l^{-1}$	0.9	0.7–1.1	0.5	0.4–0.7	0.8	0.6–0.9	0.8	0.7–1.1
Solid residue mg l^{-1}	47.7	45.6–51.4	34.8	32.3–39.7	46.3	43.3–49.1	57.8	52.1–69.5
Total hardness mg $CO_3Ca\,l^{-1}$	22.8	20.9–24.0	17.8	14.0–21.1	22.8	19.4–25.4	29.6	17.0–48.5

20% above that of the river. The values obtained allowed us to identify this ecosystem as hypohaline (total dissolved solids $\leqslant 0.5\,g\,l^{-1}$) with soft waters (hardness = 50 mg of $CO_3Ca\,l^{-1}$), neutral to slightly alkaline and of the calcium bicarbonate type. Inorganic nitrogen and phosphorus, as well as total phosphorus, were low in the river as in the lake, while mean silica in the lake decreased 20% below that of the river. Dissolved oxygen showed a uniform distribution in the water column across the study period (Fig. 4). Only during March some variation occurred, in which concentrations fluctuated from 8.5 at the surface to 4.8 mg l^{-1} in deeper layers. This depletion coincided with a slight increase in nitrate and ortophosphate. From April onwards, oxygen profiles became uniform, like the remaining variables.

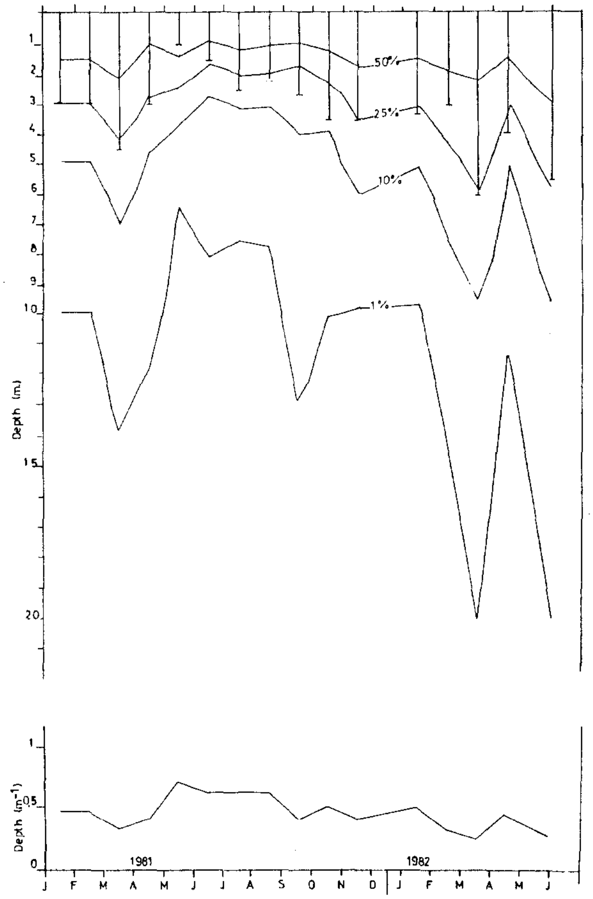

Fig. 3. Spatial-Time distribution of: a) percentage light transmission and Secchi disc depth (m), and b) extinction coefficient of light.

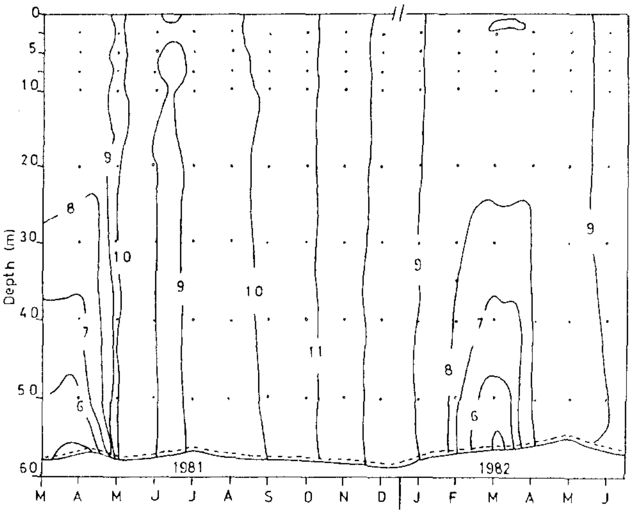

Fig. 4. Seasonal variation of dissolved oxygen (mg l^{-1}) for Ramos Mexia Reservoir.

During the study, 79 algal taxa were identified; 33 belonged to the Bacillariophyceae and 31 to the Chlorophyta (Table 3). Phytoplankton density was uniform across the water column, except in June and October 1981, and in February and March 1982. Total cells ml^{-1} oscillated from 77 (surface, July 1981) to 3900 (surface, October 1981) (Fig. 5). Integrated phytoplankton values showed three periods of high numerical density (Fig. 6). The first was in late autumn 1981 with 18.5 x 10^{9} cells m^{-2} (Table 4), with Bacillariophyceae *Melosira granulata*, *M. granulata* var *angustissima* fa. *spiralis* and *Melosira italica* as main species. The second one occurred in spring 1981 with 13.8 x 10^{9} cells m^{-2}. The Cyanophyta

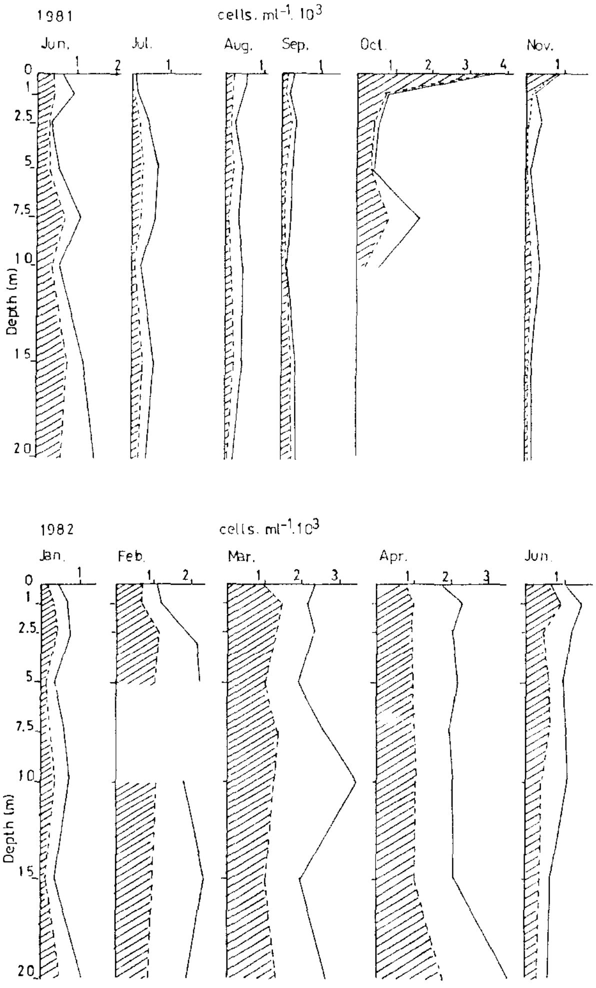

Fig. 5. Vertical distribution phytoplankton (cells ml^{-1}) for Ramos Mexia Reservoir, □ total and ▨ dominant algal group.

Table 3. Ramos Mexía Reservoir. Phytoplankton species composition

CYANOPHYTA
Anabaena circinalis Rabenh.
A. ambigua Rao
A. sp.
Oscillatoria sp.

CHLOROPHYTA
Chlamydomonas sp.
Gonium sociale (Duj.) Warm.
Pandorina morum (Muell.) Bory
Eudorina elegans Ehr.
E. sp.
Scenedesmus quadricauda (Turp.) Breb.
Sc. sp.
Crucigenia quadrata
Oocystis parva W. & G.S. West
O. eremosphaeria G.M. Smith
Coelastrum microporum Näg.
Tetraedron minimum (A.Br.) Hansg.
T. sp.
Dictyosphaerium pulchellum Wood
Botryococcus braunii Kütz
Elakatothrix gelatinosa Wille
"Chlorococcal"
Asterococcus sp.
"Tetrasporal"
Binuclearia eriensis Tiff.
Ulothrix aff. tenuissima Kütz
U. sp.
Oedogonium sp.
Mougeotia elegentula Wittr.
M. sp.
Gonatozygon monotaenium var.*pilosellum* Nordst.
Closterium aciculare T. West
C. sp.
Staurastrum sp.
Cosmarium sp.
Arthrodesmus convergens Ehr.

CHRYSOPHYTA
Bacillariophyceae
Cyclotella stelligera Cl. & Grun.
C. sp.
Stephanodiscus sp.
Melosira distans (Ehr.) Kütz
Melosira italica (Ehr.) Kütz
M. granulata (Ehr.) Ralfs
M. gran. var. angust. fa. spiralis O. Müll
M. varians C.A.Ag.
M. sp.
Rhizosolenia eriensis H.L. Smith
Asterionella formosa Hass.
Synedra ulna (Nitz.) Ehr.
S. sp.
Fragillaria sp.
Cocconeis sp.
Achnanthes sp.
Diatoma sp.
Cymbella sp.
Gomphonema herculeana Ehr.
G. acuminatum var. coronata (Ehr.) Smith
G. sp.
Rhoicosphenia curvata (Kütz) Grun.
Gyrosigma sp.
Pleurosigma sp.
Pinnularia sp.
"Naviculoide"
Epithemia sorex Kütz
E. argus Kütz
E. aff. zebra (Ehr.) Kütz
Cymatopleura solea (Breb.) W. Smith
Nitzchia sigma (Kütz) W. Smith
N. aff. sigmoidea (Ehr.) W. Smith

Chrysophyceae & Xanthophyceae
Stelexomonas dichotoma var. *arroyitensis* Echenique
Mallomonas sp.
Dynobryon divergens Imhof
D. sp.
Tribonema angustissimum Pasch.

PYRROPHYTA
Cryptomonas ovata Ehr.
Rhodomonas minuta Skuja.
Gimnodium sp.
Glenodinium sp.
"Peridinial"

EUGLENOPHYTA
Trachelomonas sp.

Anabaena circinalis prevailed, representing 80% of the community. The last and longest of the three periods occurred from late summer until early autumn 1982, with a maximum of 49.3 x 10^9 cells m^{-2} in April 1982. The Chlorophyta *Binuclearia eriensis* was the best represented species, but all groups were in steady growth from January to April. The diversity index showed temporal and spatial homogeneity (Fig. 7). However in spring, when *Anabaena circinalis* prevailed in the upper layers, the index reached its lowest value of the whole period (0.46 'bits' $cell^{-1}$).

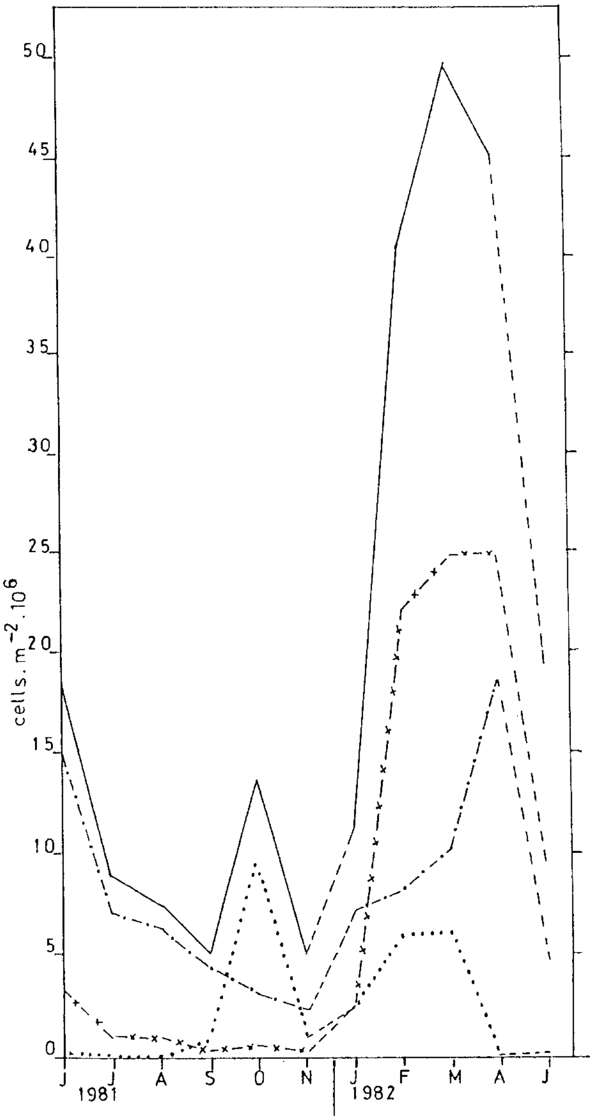

Fig. 6. Seasonal fluctuation of phytoplankton (cells m^{-2}) for Ramos Mexia Reservoir: (——) total; (–·–) Bacillariophyceae; (–×–) Chlorophyta and (......) Cyanophyta.

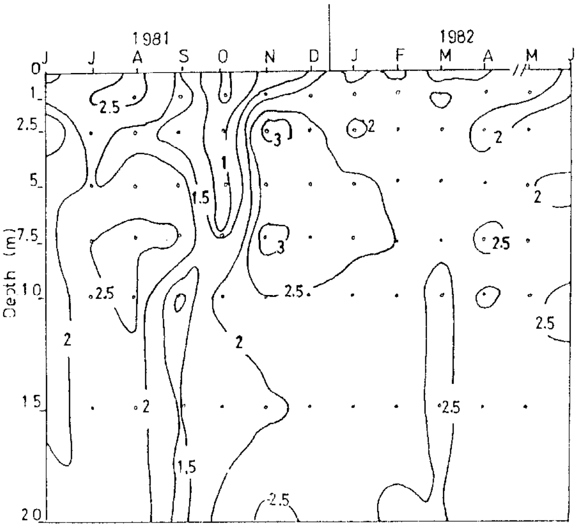

Fig. 7. Phytoplankton species diversity (bits cells^{-1}) for Ramos Mexia Reservoir.

Chlorophyll *a* concentrations were generally uniform across the water column, and never exceeded 3 mg m^{-3} (Fig. 8). Integrated values up to 10 meters deep varied between 6 and 28 mg m^{-2} (Table 5). Phaeopigment concentrations relative to chlorophyll *a* never surpassed 22%, with a maximum of 3.5 mg m^{-2} in April 1982. The contribution of phytoplankton below 25 μm size to total chlorophyll reached a maximum of 76% in January 1982 and oscillated from 10 to 50%. The lowest value was 7% during February 1982 (Table 5).

The pigment index also showed uniformity across the water column, with values ranging between 2.7 and 3.0 (Fig. 9).

The highest production values were observed between 1 and 5 meters depth (the peak was 13.9 mg C m^{-3} h^{-1} during February 1981 at 2.5 meters, and was followed by a quick decrease (Fig. 10). An area of photoinhibition between the surface and 1 meter was frequently observed. Optimum production occurred around 25% of incident light. High values coincided with sum-

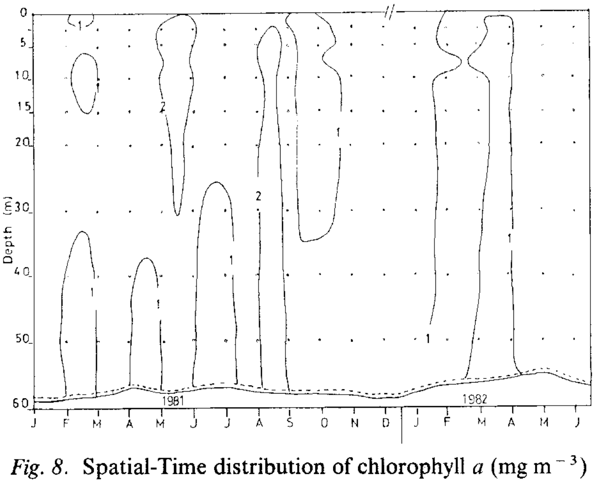

Fig. 8. Spatial-Time distribution of chlorophyll *a* (mg m^{-3}) for Ramos Mexia Reservoir.

Table 4. Ramos Mexía Reservoir. Monthly distribution of phytoplankton (cells × 10^9 m^{-2}).

	Chlorophyta	*Cyanophyta*	*Bacillariophyceae*	*Chrysophyceae Xanthophyceae*	*Pyrrophyta*	Total
Jun.	3.282	0.122	15.141	–	–	18.461
Jul.	1.089	–	7.080	–	0.036	9.049
Aug.	0.988	–	6.276	0.021	0.251	7.536
Sept.	0.304	0.713	4.645	0.006	–	5.685
Oct.	0.506	9.670	3.046	0.137	0.060	13.601
Nov.	0.386	0.920	2.246	0.555	0.982	5.197
Jan.	2.110	2.476	6.994	0.848	0.213	12.646
Feb.	21.804	6.122	8.122	2.393	2.224	40.616
Mar.	24.820	6.145	10.162	6.722	1.532	49.315
Apr.	24.585	–	18.632	1.169	0.679	45.115
Jun.	11.013	0.197	4.504	0.600	2.874	19.163

mer, reaching 106.9 mg C m^{-2} h^{-1} in February. Rates were around 25 mg C m^{-2} h^{-1} throughout the rest of the period, being lowest in spring. Phytoplankton below 25 μm contributed from 18 to 64% to total primary production (Fig. 10).

Discussion and conclusions

Limay River is the major contributor of nutrients and salts to the water of the reservoir. An increase in residence time increases salinity, either due to evaporation or to turbulence, diffussion or other processes at the water/sediment interphase.

Temperature data show that the lake is in almost permanent circulation. Stratification of dissolved oxygen only appeared during March, but surface supersaturation did not occur, as typical for oligo- to mesotrophic lakes (Golterman, 1975; Margalef, 1976). The uptake of oxygen by microbial activity close to the bottom leads to a slight increase in ortophosphate and nitrate in sample from 1 meter above bottom.

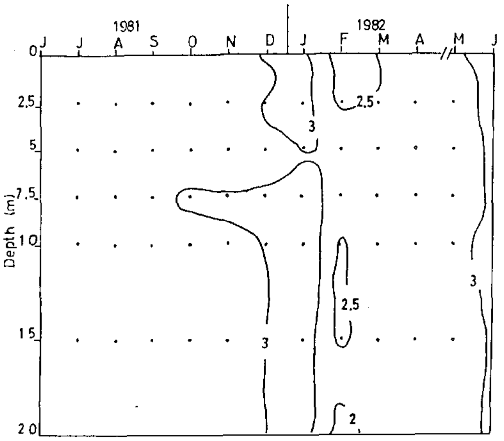

Fig. 9. Distribution of photosynthetic pigment index (D430/D665) for Ramos Mexia Reservoir.

Winds blow mainly from the west along the lake's longitudinal axis. They cause the vertical mixing, which allows a transfer of nutrients to the euphotic zone and a resuspension of particulate matter. A low transparency and shallow photic zone result, causing a low numerical density of phytoplankton and chlorophyll. Primary production is therefore also restricted to the upper layers. Photosynthesis neither modifies pH nor produces a shift in the CO_2-carbonate system. Maximum algal activity, or primary production expressed per unit of chlorophyll, was observed between 1 and 5 meters depth and varied between 1.7 and 13.0 with a mean of 4.3 mg C (mg chlorophyll $a)^{-1}$ h^{-1}. High values occurred in summer and were determined in part by temperature, which is higher in the reservoir than in the natural glaciar lakes of the river basin, where production is smaller (Maglianesi *et al.*, 1973).

Nannoplankton contribution to total primary production was important during some periods (more than 50%).

Inorganic nitrogen and phosphorus as well as total phosphorus were low, generating an equally

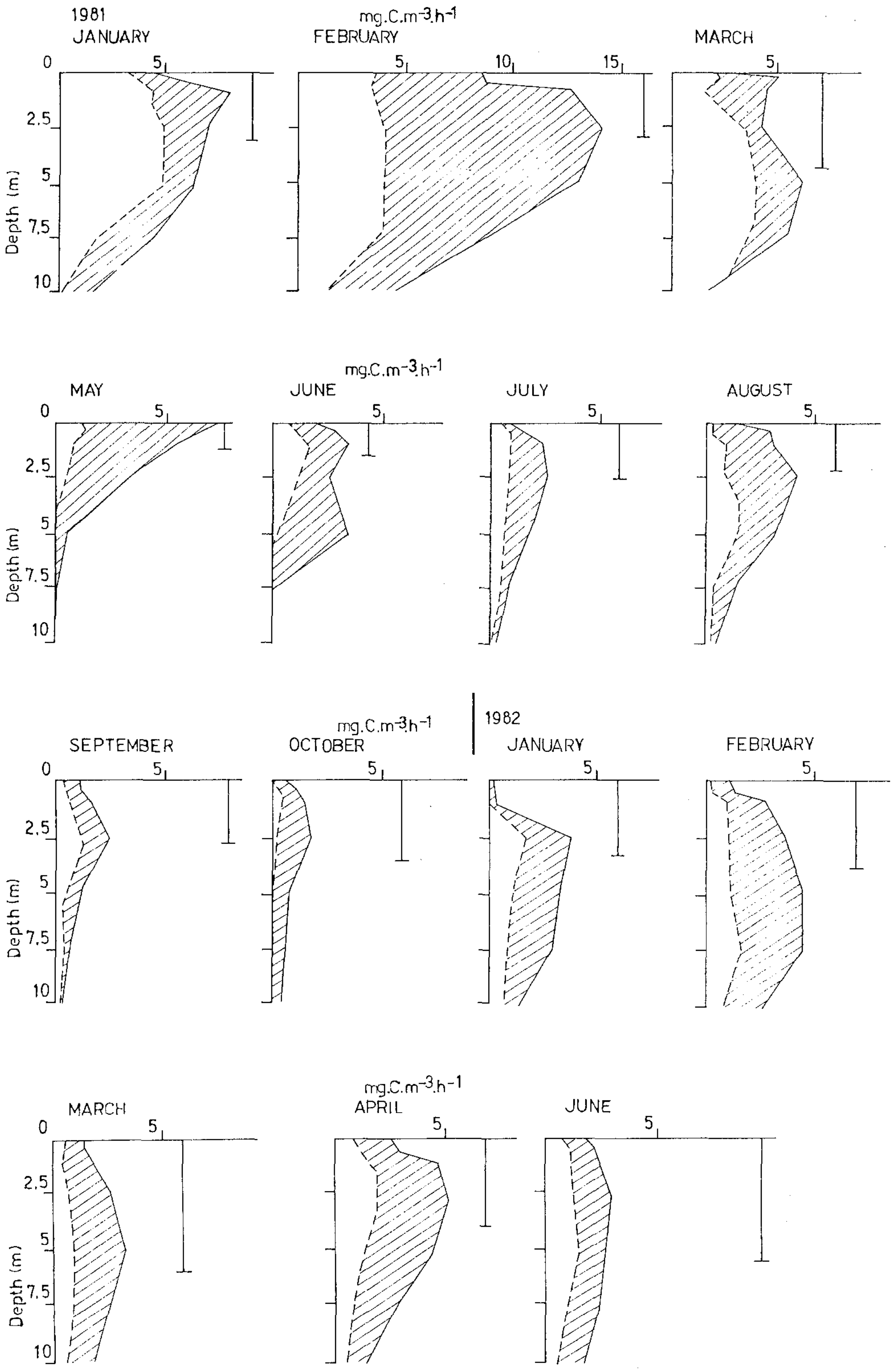

Fig. 10. Vertical distribution of primary production for Ramos Mexia Reservoir: ▨ total phytoplankton and ☐ below 25 μm fraction (⊥) Secchi disc depth.

scarce algal biomass. In agreement with Reynolds & Walsby (1975), low nutrient concentration and short residence time produced few taxa, belonging to the Cyanophyta. However *Anabaena circinalis*, during 'climatic calm' periods, became numerically significant, even producing blooms. Reactive silica was present in concentrations that do not limit Bacillariophyceae. The low values observed in relation to the river were either due to uptake or to precipitation produced by salinity changes.

Specific diversity data fall between oligo and mesotrophic environments, according to Margalef (1977), and chlorophyll *a* concentrations are typical of oligotrophic lakes (Aruga, 1973; Vollenweider *et al.*, 1974). The pigment index situates this ecosystem in the group with low eutrophy, resembling the values obtained by Margalef *et al.* (1976) for a series of Spanish dams.

The majority of the variables surveyed characterize the lake as oligo to mesotrophic. A low concentration of nutrients and a short water residence time are the main factors responsible of its low degree of maturity.

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